TERPOLYMER SYSTEMS FOR ELECTROMECHANICAL AND DIELECTRIC APPLICATIONS

This application claims priority from U.S. Provisional Application No. 60/280,303, filed Mar. 30, 2001, and is a continuation-in-part application of U.S. Ser. No. 09/195,061, filed Nov. 18, 1998, now U.S. Pat. No. 6,423,412.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to polymeric materials with elevated electric field induced strain levels, elevated elastic energy densities, and having elevated dielectric constants at room temperature. The material can be used in electromechanical devices which convert electric energy into mechanical energy or convert mechanical energy into electric energy. Material of the invention can also be used as a capacitor which stores electric energy and regulates electric voltage in a circuit.

2. Description of the Prior Art

Both polymers and inorganic materials (such as ceramics) have been used widely in electromechanical devices such as actuators, transducers, artificial muscles and robots. However, in the currently available commercial materials, the strain level and elastic energy density both are quite low (strain ~0.1% and elastic density ~0.1 J/cm^3), which causes many problems for device performance. For example, in order to generate large actuation, in many current devices, an amplification scheme has to be used. In addition, the low elastic energy density also reduces the force and power output of the electromechanical devices. In order to improve the performance of a wide variety of electromechanical devices, it is required that the electric field induced strain level and elastic energy density be improved.

Polymers are also used widely in capacitors for high voltage operation and charge storage. However, the dielectric constant of the current commercial polymers is quite low (below 10). A high dielectric constant polymer can reduce the capacity volume and charge storage capability of the capacity.

In spite of their advantages over the ceramics, current polymers suffer low field sensitivities, such as dielectric constant, piezoelectric coefficient, electromechanical coupling factor and field induced strain. These constraints severely limit the application of ferroelectric polymers as transducers, sensors and actuators.

There is a demand for improved materials for use in actuators and transducers due to the limitations of currently available materials. For example, current actuator materials, such as electrostatic, electromagnetic and piezoelectric materials, exhibit limitations in one or more of the following performance parameters: strain, elastic energy density, speed of response and efficiency. For instance, piezoceramic and magnetostrictive materials, while possessing low hysteresis and high response speeds, suffer from low strain levels (~0.1%). Shape memory alloys generate high strain and high force but are often associated with large hysteresis and very slow response speeds. On the other hand, there are several polymers such as polyurethane, polybutadine etc. which can generate high electric field induced strain i.e. up to 6–11%. But, due to their low elastic modulus, their elastic energy density is very low. Further, the strain generated in these materials is mainly due to the electrostatic effect, which is a low frequency process. Use of these materials at high frequencies reduces their response drastically. In addition, due to their low dielectric constant, the electric energy density of these polymers is very low which is an undesirable characteristic for many transducer and actuator applications.

Substantial efforts have been devoted to improvement of phase switching materials where an antiferroelectric and ferroelectric phase change can be field induced to cause a high strain in the material. While strains higher than 0.7% have been achieved in such materials, due to the brittleness of ceramics, severe fatigue has been found to occur at high strain levels. Recently, in a single crystal ferroelectric relaxor, i.e., PZN-PT, an electric field strain of about 1.7%, with very little hysteresis, has been reported, which is exceptionally high for an inorganic materials (see: Park and Shrout, J Appl. Phys., 82, 1804 (1997)). In such ceramic materials, mechanical fatigue occurs at high strain levels, a major obstacle limiting their use for many applications.

For many applications, such as microrobots, artificial muscles, vibration controllers, etc., higher strain levels and higher energy densities are required. Thus, there is a need for a general purpose electroactive material with improved performance for use with transducer and actuators.

There is a further requirement for improved ultrasonic transducers and sensors for use in medical imaging applications and low frequency acoustic transducers. Current piezoceramic transducer materials, such as PZTs, have a large acoustic impedance (Z>35 Mrayls) mismatch with the air and human tissue (Z<2 Mrayls). On the other hand, piezoelectric polymers such as P(VDF-TrFE), PVDF not only have an acoustic impedance well matched (Z<4 Mrayls) to human tissue but also offer a broad nonresonant frequency bandwidth. But, because of their low piezoelectric activity and low coupling coefficient, the sensitivity of such ultrasonic polymer transducers is very low.

The capacitor industry also requires a capacitor which has a much higher electric energy density than is currently available. Current dielectric materials, such as polymers, have a low dielectric constant (~2–10) and limited energy density. In addition, with current ceramics, the maximum field which can be applied is limited.

Accordingly, it is an object of the invention to provide a polymeric material which can generate a high electric field-induced strain with little hysteresis.

It is another object of the invention to provide a polymeric material which exhibits a high elastic energy density.

It is yet another object of the invention to provide a polymeric material that exhibits a room temperature dielectric constant that is higher than other currently available polymers.

These and other objects and advantages of the present invention and equivalents thereof, are achieved by compositions for electrical or electomechanical devices.

SUMMARY OF THE INVENTION

The present invention provides polymers prepared by a polymerizing a mixture of three monomers comprising: at least one monomer of vinylidene-fluoride; at least one monomer selected from the group consisting of trifluoroethylene and tetrafluoroethylene; and at least one monomer selected from the group consisting of tetrafluoroethylene, vinyl fluoride, perfluoro (methyl vinyl ether); bromotrifluoroethylene, chlorofluoroethylene, chlorotrifluoroethylene, and hexafluoropropylene. Polymers of the invention exhibit an electrostrictive strain, at room temperature, of 3% or more when an electric field gradient